Optimizing GELI Performance

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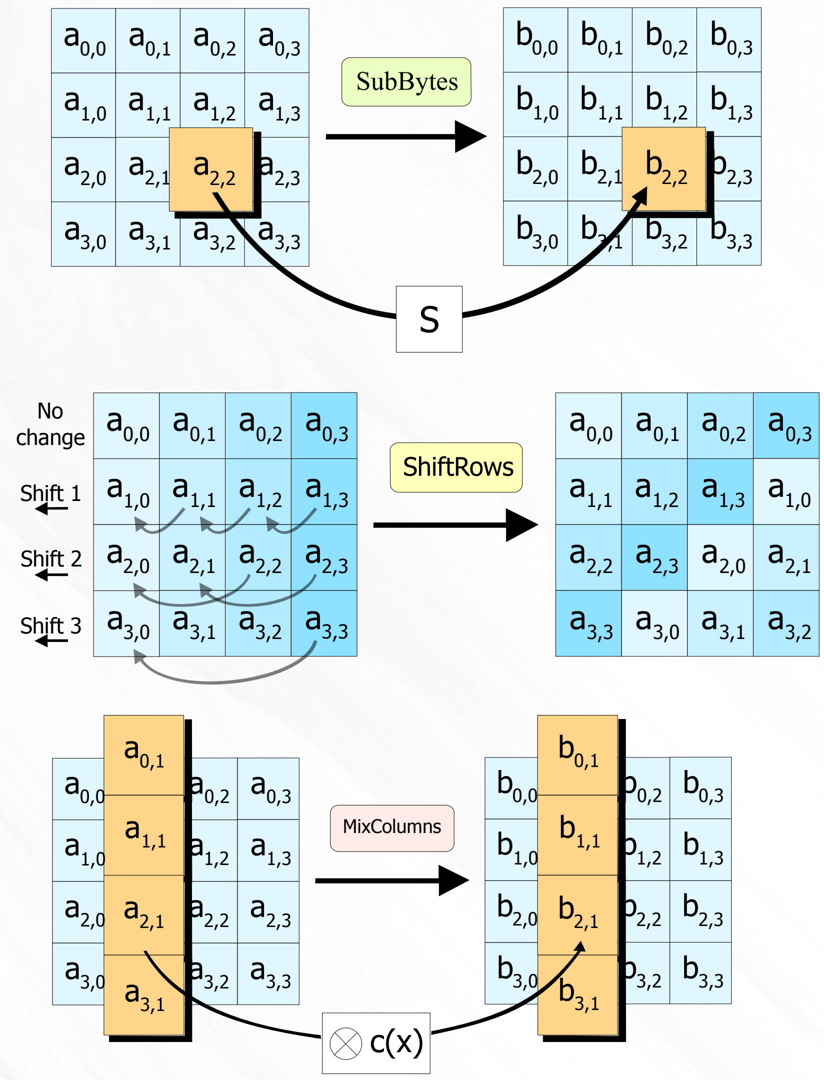
Why improve it?

- Even w/ 6 cores, ZFS+GELI was slow
- AES-NI did not significantly improve things
    - GELI is using AES-XTS, which should get >1GB/sec, but only got <150MB/sec (in userland testing)
- If it's slow, people won't use it
- Make it more maintainable

What is AES?

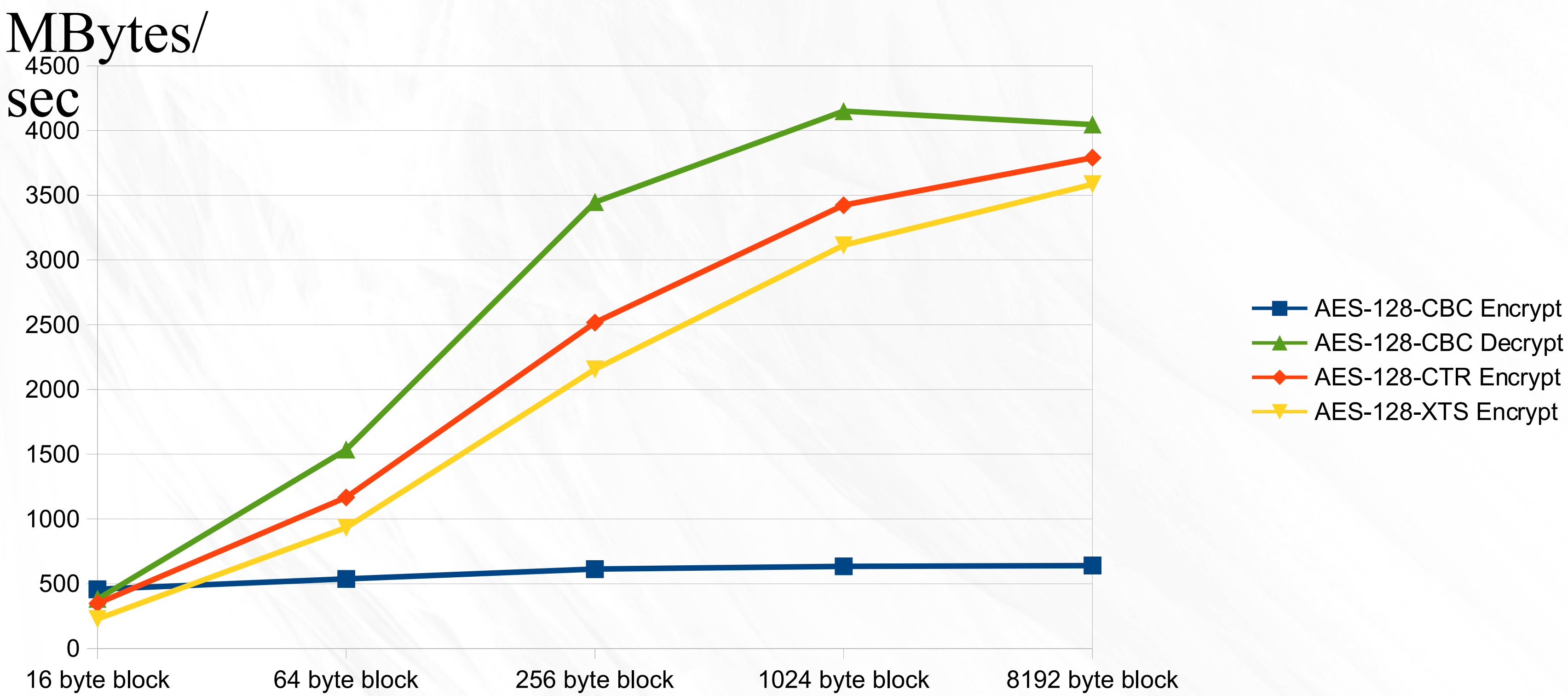
- Initial Round
  - AddRoundKey
- Rounds
  - SubBytes
  - ShiftRows
  - MixColumns
  - AddRoundKey
- Final Round
  - SubBytes
  - ShiftRows
  - AddRoundKey



Setting the correct options

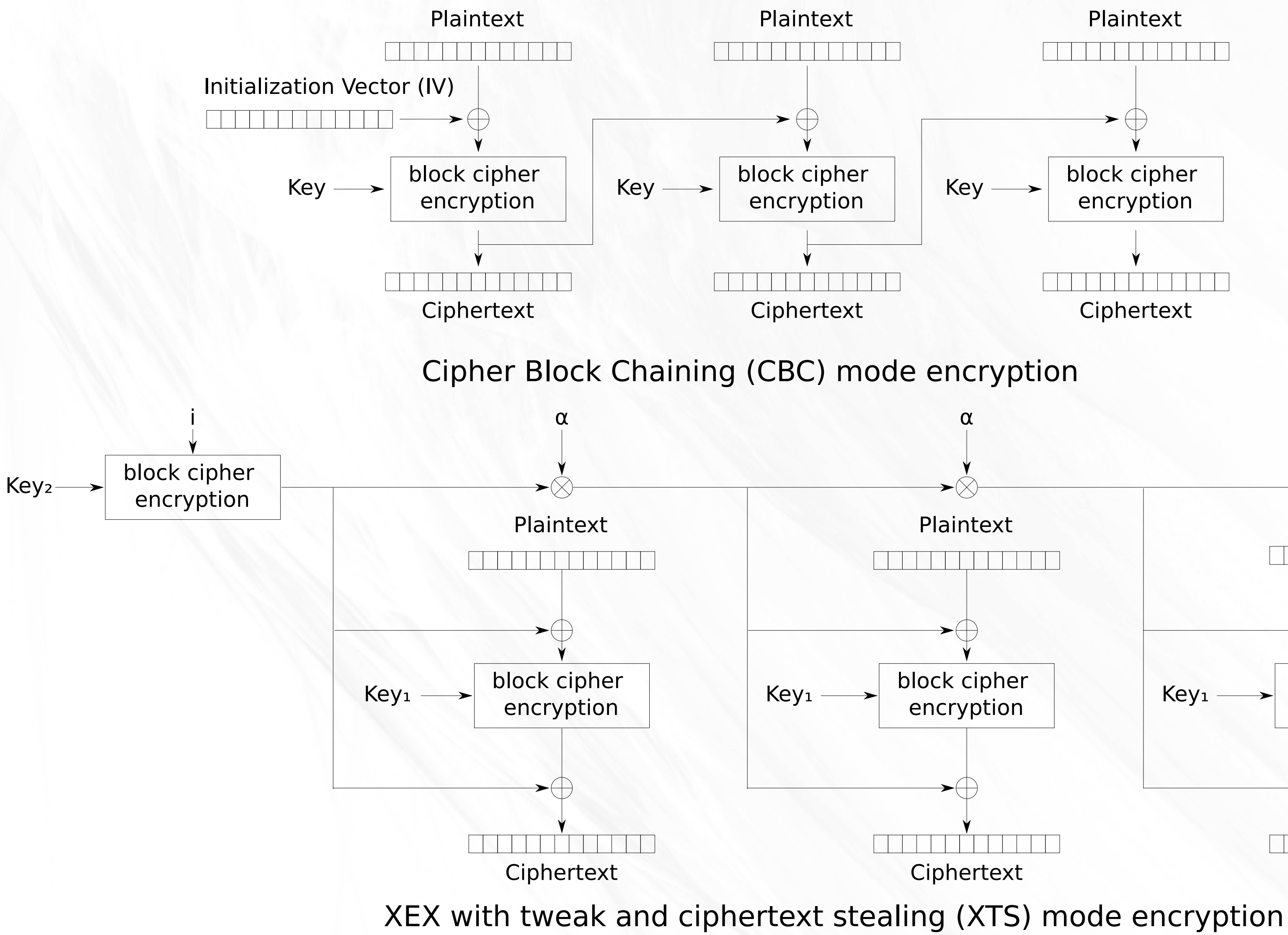
- Cipher Mode
- Sector Size
- Key Size (sets number of rounds)

OpenSSL Baseline Performance

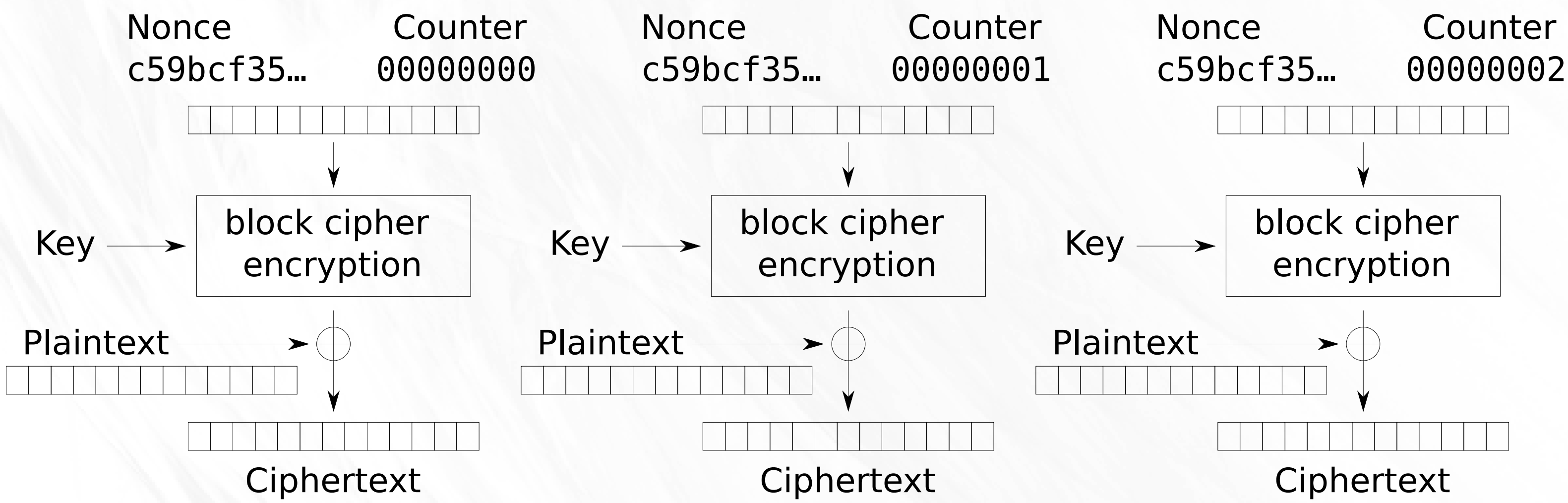


Make sure you specify -evp to openssl speed to get AES-NI

Cipher Mode could be the issue



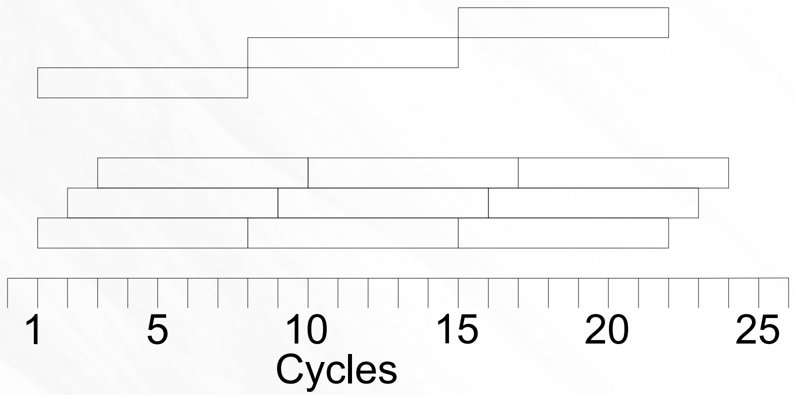
Counter Cipher Mode



Counter (CTR) mode encryption

Instruction Pipelining

- AES has 10, 12 or 14 rounds depending upon key size
- Each round depends upon previous round
- Multiple blocks can (if mode supports it) be done at the same time



Improving the Tweak Factor

Original code:

```
uint8_t *tweak; /* parameter */

/* Exponentiate tweak. */

carry_in = 0;

for (i = 0; i < AES_XTS_BLOCKSIZE; i++) {

        carry_out = tweak[i] & 0x80;

        tweak[i] = (tweak[i] << 1) | (carry_in ? 1 : 0);

        carry_in = carry_out;

}

if (carry_in)

        tweak[0] ^= AES_XTS_ALPHA;
```

Improving the Tweak Factor

pjd's improved code:

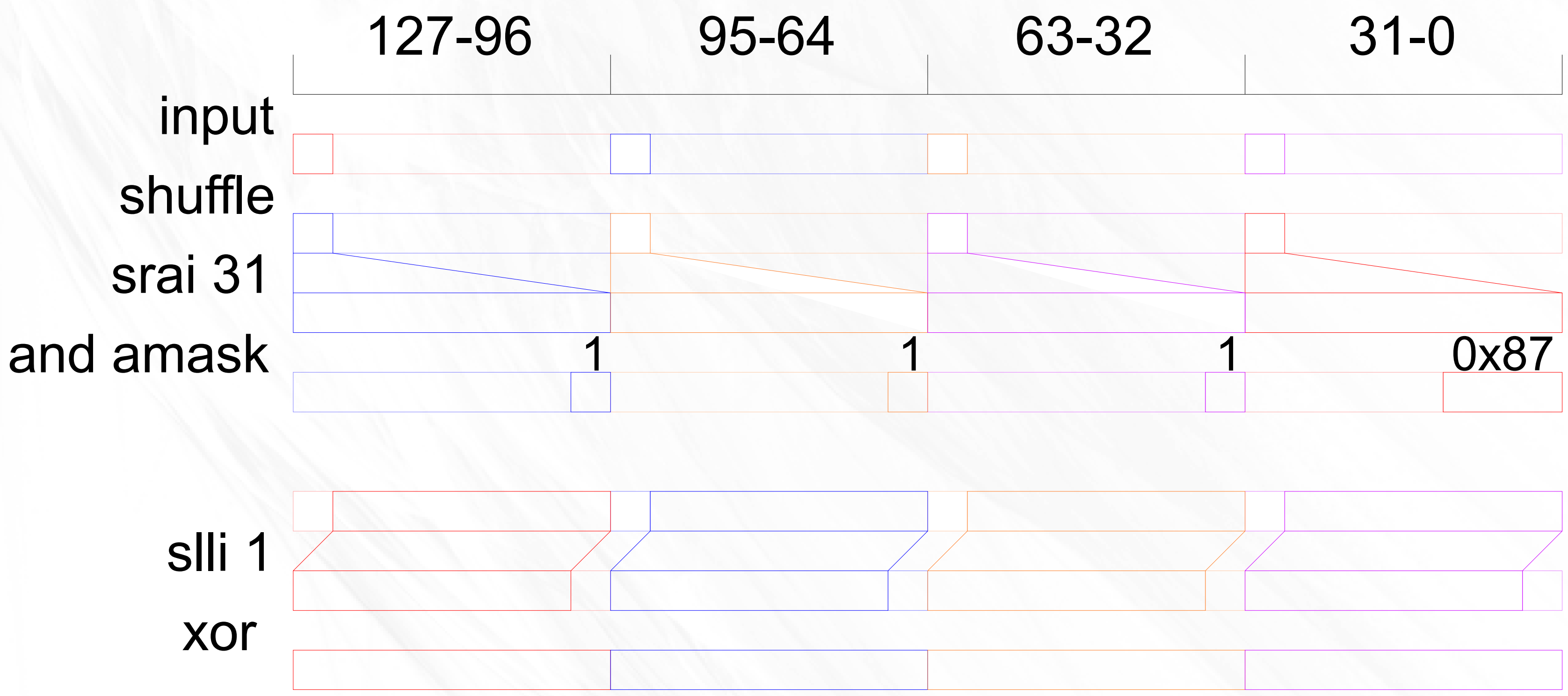
```
uint64_t *tweak; /* parameter */

/* Exponentiate tweak. */

carry = ((tweak[0] & 0x8000000000000000ULL) > 0);

tweak[0] <<= 1;

if (tweak[1] & 0x8000000000000000ULL) {

        uint8_t *twk = (uint8_t *)tweak;

        twk[0] ^= AES_XTS_ALPHA;

}

tweak[1] <<= 1;

if (carry)

        tweak[1] |= 1;
```

Improving the Tweak Factor

Current code:

```
    __m128i inp, ret;
    const __m128i alphamask = _mm_set_epi32(1, 1, 1,
AES_XTS_ALPHA);
    __m128i xtweak, ret;
    /* set up xor mask */
    xtweak = _mm_shuffle_epi32(inp, 0x93);
    xtweak = _mm_srai_epi32(xtweak, 31);
    xtweak &= alphamask;
    /* next term */
    ret = _mm_slli_epi32(inp, 1);
    ret ^= xtweak;
```

Tweak factor of AES-XTS



Intrinsics vs Assembly

- Intrinsics Pros
  - Works around ABI limitations
  - Inline functions
  - Single source for i386 and amd64
  - Maintainability
- Assembly Pros
  - Tighter instruction scheduling
  - Easier non-aligned load control
  - gcc did not support AES-NI intrinsics

Adding AES-NI to toolchain

- clang did not need any work
- Our gcc/binutils is *very* old (tell me something I don't know)
- Added support to binutils for assembling AES-NI instructions
- gcc needed new headers
- PCLMULDQD (carry-less multiple) added for completeness

Original Assembly

```
     movdqu   (%rdx),%xmm0
     cmpq     $0,%r8
     je       1f
     movdqu   (%r8),%xmm1  /* unaligned load into reg */
     pxor     %xmm1,%xmm0  /* pxor otherwise can fault on iv */
1:   pxor     (%rsi),%xmm0
2:   addq     $0x10,%rsi
//   aesenc   (%rsi),%xmm0
     .byte    0x66,0x0f,0x38,0xdc,0x06
     decl     %edi
     jne      2b
     addq     $0x10,%rsi
//   aesenclast (%rsi),%xmm0
     .byte    0x66,0x0f,0x38,0xdd,0x06
     movdqu   %xmm0,(%rcx)
```

Intrinsics

- Provides a 128 bit data type (__m128i and others)
- Implements functions as either a built-in or asm directive in header files
- Features must be enabled via compiler flag
- Not easy to handle unaligned data – use either:
  - explicit _mm_loadu_si128 call
  - access through a packed struct

Intrinsic Code

```
static inline __m128i aesni_enc(int rounds, const
__m128i *keysched, const __m128i from)
{
   __m128i tmp;
   int i;

   tmp = from ^ keysched[0];
   for (i = 0; i < rounds; i++)
      tmp = _mm_aesenc_si128(tmp, keysched[i + 1]);
   return _mm_aesenclast_si128(tmp, keysched[i + 1]);
}
```

Adding to kernel compile

- Special rule in sys/conf/files.{amd64,i386} to enable AES-NI

```
aesni_wrap.o     optional aesni          \
        compile-with    "${CC} -c           \
        ${CFLAGS:C/^-O2$/-O3/:N-nostdinc} \
        ${WERROR} ${PROF}               \
        -mmmx -msse -maes ${.IMPSRC}" \
```

Performance Testing

- ministat

```
x aesni.sync.nowit.txt
+ aesni.txt
* software.txt
+--------------------------------------------------------------------------------+
| *                                                          +                  x |
|**                                                          +                 xx|
|**                                                          +                 xx|
||A                                                          A                 A||
+--------------------------------------------------------------------------------+
    N           Min           Max        Median           Avg        Stddev
x   5 7.1846125e+08 7.2917070e+08 7.2324988e+08 7.2420199e+08     4489811.8
+   5 5.4985213e+08 5.5033968e+08 5.5013242e+08 5.5012183e+08     196393.65
Difference at 95.0% confidence
        -1.7408e+08 +/- 4.63466e+06
        -24.0375% +/- 0.639967%
        (Student's t, pooled s = 3.17781e+06)
*   5      55667911      63067447      60749919      60422098     3022659.1
Difference at 95.0% confidence
        -6.6378e+08 +/- 5.58175e+06
        -91.6567% +/- 0.770745%
        (Student's t, pooled s = 3.8272e+06)
```

Using pmcstat

- Generate performance data:

```
pmcstat -P BU_CPU_CLK_UNHALTED -o
  pmcstat.out -g ./test perf
```

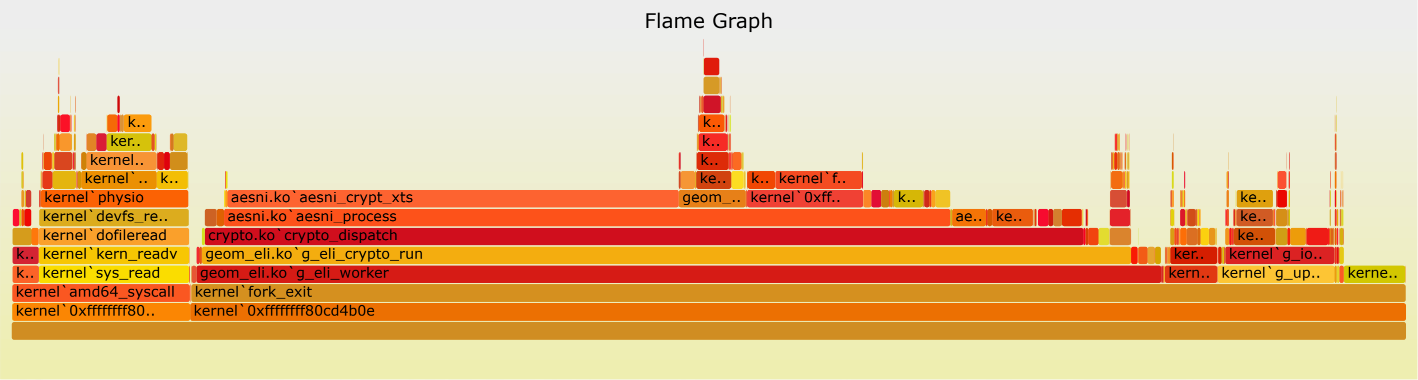
- gprof format output cannot handle large counts
- calltree (kcachegrind) format to the rescue

```
pmcstat -R pmcstat.out -F
  output.calltree
```

Performance Testing

- Call graph showed unexpected thread crypto_ret_proc consuming ~15% cpu
- Thread runs to deliver callbacks, if AES-NI driver is marked CRYPTOCAP_F_SYNC, callbacks are not deferred to thread, resulting in ~27% performance increase

GELI on gzero performance



- debug.witness.watch=0
- kern.geom.eli.threads=1
- kern.geom.zero.clear=0
- ~900MB/sec on AMD A10-5700 3.4GHz

Continued Improvement

- Only calls through OpenCrypto framework are improved, direct calls are not
  - Handling FPU state in non-sleepable contexts
- Better memory allocation, avoid large allocs
- Pipeline key schedule – AES-XTS needs two
- AES-GCM – Work ongoing and supported by the FreeBSD Foundation and Netgate
- Working on SHA256 (for ZFS)

Questions?